A research of infectivity rate After the Consecutive Holidays

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Abstract

I proposed a discrete mathematical SEPIR model for seasonal influenza. In this study, by examining affection by pre-infectious students in real data, I found that super-spreading depends on the timing of penetration. I show the students that super-spread seasonal influenza according to the day the first patients are discovered. According to the data, on average it takes for days for seasonal influenza measures to be implemented within the communities.

Keywords: Epidemic model, Flu, super-spread, infectivity rate.

1. Introduction

An epidemic of Flu: seasonal influenza occurred at JCGA: Japan Coast Guard Academy in January, 2017. After three consecutive holidays from January 7th to 9th, students returned to the dormitory and started taking classes. On Friday January 13th, two students developed Flu. At that time, there were 150 undergraduate students. Finally, 37 students, 20 freshmen, 13 sophomores and 4 juniors developed the Flu [1]. Of the 60 teachers not one developed Flu. According to our medical doctor at that time, usually about five students develop Flu at the dormitory in a usual epidemic wave.

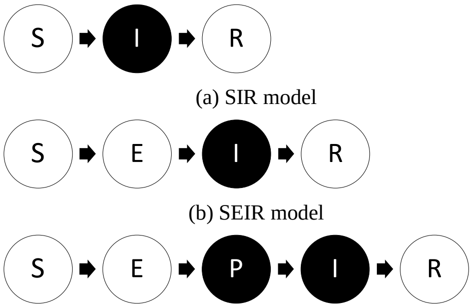
An epidemic of SARS: Severe Acute Respiratory Syndrome occurred in Singapore in 2003[2]. Five people were categorized as super spreaders of SARS who directly affected more than ten people. At JCGA, I also found the super-spreading of Flu. In this paper, I show super-spreading according to the day that first patients are discovered. Here, I define super-spreading as that of more than certain number students which are directly affected.

2. Mathematical Model

Kermack et.al proposed SIR model for epidemics[3]. The state transition diagram of an individual is shown in Fig. 1(a). “S”, “I” and “R” means susceptible state, infectious state and recovered state. An individual of “S” can transit to “I” by contact with individual of “I”. Then, an individual moves state from “I” to "R" depending on how long it has been in “I”.

Keeling et.al[4] introduced the incubation period, that is exposed “E” state into SIR model and proposed mathematical SEIR model, which many childhood infectious diseases follow. Individual of “E” is affected but not yet infectious. Only individual of “I” can affect individual of “S”. The state transition diagram of an individual is shown in Fig. 1(b).

At JCGA, students are not affected by students of “I” because patients are isolated in sick rooms. Then, I introduced pre-infectious state “P” into SEIR model and proposed the discrete mathematical SEPIR model for Flu[1]. The incubation period is divided into two periods, the exposed period and the infectious period, but neither have any symptoms. I set the former as exposed state “E”



(a) SIR model

(b) SEIR model

(c) SEPIR model

Fig. 1. The state transition diagram of an individual: circle shows state of individual. S: Susceptible state, E: Exposed state, P: Pre-infectious state, I: Infectious state and R: Recovered state. Black circle means that it can affect others.

and the latter as pre-infectious state "P". The state transition diagram of an individual is shown in Fig. 1(c).

$$\Delta S = S(t+1) - S(t) = -\alpha S(t)P(t) - \beta S(t)I(t) \quad (1)$$

$$\Delta E = E(t+1) - E(t) = \alpha S(t)P(t) + \beta S(t)I(t) - \sigma E(t) \quad (2)$$

$$\Delta P = P(t+1) - P(t) = \sigma E(t) - \tau P(t) \quad (3)$$

$$\Delta I = I(t+1) - I(t) = \tau P(t) - \gamma I(t) \quad (4)$$

$$\Delta R = R(t+1) - R(t) = \gamma I(t) \quad (5)$$

Individual of "I" or "P" can affect individual of "S". There is some contact between individual of "S" and that of "I". The probability of the contact is determined by the respective numbers of "S" and "I". Considering a mean infectivity rate β, individual of "S" moves "E" as given in Eq (1)[3]. There is also some contact between individual of "S" and that of "P". The probability of the contact is determined by the respective numbers of "S" and "P". By introducing infectivity rate α, individual of "S" moves "E" as given in Eq (1)[1]. By introducing transmission rate σ, individual of "E" moves "P" as given in Eq (2)[1]. By introducing transmission rate τ, individual of "P" moves "I" as given in Eq (3)[1]. By introducing the recovery rate γ which is the inverse of the infectious "I" period, this leads to a far more straightforward equation as shown in Eq (4)[3]. Here, S(t), E(t), P(t), I(t) and R(t) is the number of individuals of "S", "E", "P", "I" and "R". I set a base time as 08:30 and t represent days since January 9.

3. Former Results[1]

I have the JCGA data of developed students as shown by "I" in Table 1 (Case A). First column ID shows student identification number and next 18 columns show the daily state of the student. The date with underline means day off. The average of infectious "I" period is 3.86 days.

Table 1. Epidemic of Flu at JCGA in January, 2017 (Case A).

ID	<u>9</u>	10	11	12	13	<u>14</u>	<u>15</u>	16	17	18	19	20	21	<u>22</u>	23	24	25	26	F	C	B	Y
1	S	E	P	P	**I**	I	I	I	R	R	R	R	R	R	R	R	R	R	16	16	0	O
2	S	E	P	P	**I**	I	I	I	R	R	R	R	R	R	R	R	R	R	11	9	2	O
3	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	R	7	6	1	U
4	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	R	6	6	0	U
5	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	R	6	6	0	U
6	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	R	6	6	0	U
7	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	R	R	R	8	6	2	U
8	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	0	0	0	X
9	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	1	0	1	X
10	S	S	S	E	P	P	<u>I</u>	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
11	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	2	0	2	X
12	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
13	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	1	0	1	X
14	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
15	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
16	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
17	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	U
18	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	1	0	1	X
19	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	R	1	0	1	X
20	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	R	R	0	0	0	X
21	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	R	R	0	0	0	X
22	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	0	0	0	X
23	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	0	0	0	X
24	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	0	0	0	X
25	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
26	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	R	0	0	0	X
27	S	S	S	S	E	P	P	I	I	R	R	R	R	R	R	R	R	R	0	0	0	X
28	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	0	0	0	X
29	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	1	1	0	X
30	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	1	1	0	X
31	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	1	1	0	O
32	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	0	0	0	X
33	S	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	1	1	0	X
34	S	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	0	0	0	O
35	S	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	1	1	0	O
36	S	S	S	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	0	0	0	X
37	S	S	S	S	S	S	S	S	S	E	P	P	I	I	I	I	I	R	0	0	0	X
I	0	0	0	0	**2**	7	21	27	25	27	12	9	7	3	1	1	1	0				
P	0	2	7	21	25	21	13	8	8	3	2	1	0	0	0	0	0	0				
G	-	-	13	6	1	4	0	1	1	0	0	0	-	-	-	-	-	-				
CG	-	-	13	6	0	0	0	0	0	0	0	0	-	-	-	-	-	-				
BG	-	-	2	3	1	4	0	0	0	0	0	0	-	-	-	-	-	-				

I found that student 1 and 2 brought Flu to the JCGA, which is called the source of the infection. I supposed that a student is affected in their room, which is a closed space and follows the SEPIR model. By retrospective investigation of activities in closed spaces according to the schedule of students, I found that it was on campus transmission. As for infection channels, I found I just had to deal with bedrooms and classrooms as closed spaces. As for the incubation period, focusing on student of "E", I found the period of "E" is one day and the period of "P" is two days. Then, I filled in the state of the students, such as "S"," E", "P" and "R", in Table 1, as well.

4. JCGA 2017 Case

I reconfirmed to focus on the affected students by student of "P". In Table 1, F, C and B columns refer to the number of affected students by student of "P" at JCGA, in classrooms and in bedrooms. F and C of students 1 or 2 are very high. And C is more than B because students in classrooms are more than that of bedrooms. Here, F is not equal to the sum of C and B because students can affect the same student in both rooms.

I and P rows refer to the number of students of "I" and "P". I on January 13th is the most and P on January 16th or 18th is the most. G, CG and BG rows refer to the number of affected students by student of "P" at JCGA, in classrooms and in bedrooms on that day. G on January 11th or 12th is very high. CG is more than BG because students in classrooms are more than that of bedrooms. Here, G is not equal to the sum of CG and BG because students can be affected in both rooms on that day. Y means infection channel. "O" refers to outside of JCGA on weekends. "X" refers to campus transmission and 26 students of "X" derived from student 1 and 2. "U" refers to unknown.

5. JCGA 2019 Cases

In January 2019, an epidemic of Flu also occurred on JCGA training ship. Here, I define epidemic as the case that patients are more than first patients. After winter vacation until January 3rd, students returned to the dormitory and started embarkation training. At that time, there were 56 freshmen on the JCGA training ship. On Friday January 10, a student, the source of infection developed Flu. Finally, 18 students were affected. Developed students are shown by "I" in Table 2 (Case B). According to former study[1], I filled in the state of students such as "S"," E", "P" and "R", as well. F, C, B, Y, I, P, G, CG and BG are the same as in Table 1. Here, base time is 10:00. I found that F and C of student 1 or 2 is very high and G and CG on January 9th or 10th are very high. C is more than B and CG is more than BG. And G on January 12th is small though P is most.

In the two cases, it seems that the source students developed Flu at the very beginning and super-spread the virus. Here, I define super-spreading as that of more than five students directly affected at JCGA, because JCGA is a small academy. I found that the source students affected many students according to the day of the first patients being discovered, hereinafter referred to D-day. After D-day, even though P is large, G is small, few students were affected. At that time, the preventative measures against epidemic students were adapted after D-day, such as wearing medical masks, hand washing and ventilation. The measures seemed to be effective. Moreover, I found that about four days after the consecutive holidays, namely the incubation period passing, the first patients were discovered.

Table 2. Epidemic of Flu on JCGA embarkation training ship in January, 2019 (Case B).

ID	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	F	C	B	Y
1	S	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	6	6	4	O
2	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	12	12	7	U
3	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	R	R	7	7	4	X
4	S	S	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	2	2	2	X
5	S	S	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	2	2	2	X
6	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	2	2	2	X
7	S	S	S	S	S	E	P	P	I	I	I	I	I	I	R	R	R	R	2	2	2	X
8	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	R	R	R	2	2	2	X
9	S	S	S	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	2	2	2	X
10	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	2	2	2	X
11	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	2	2	2	X
12	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	2	2	2	X
13	S	S	S	S	S	S	E	P	P	I	I	I	I	I	R	R	R	R	2	2	2	X
14	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	2	2	2	X
15	S	S	S	S	S	S	E	P	P	I	I	I	I	R	R	R	R	R	2	2	2	X
16	S	S	S	S	S	S	S	S	E	P	P	I	I	I	R	R	R	R	0	0	0	X
17	S	S	S	S	S	S	S	S	E	P	P	I	I	R	R	R	R	R	0	0	0	X
18	S	S	S	S	S	S	S	S	S	S	S	S	S	S	E	P	P	I	0	0	0	U
I	0	0	0	0	0	**1**	2	3	8	15	15	12	12	4	0	0	0	1				
P	0	0	0	1	2	2	6	12	7	2	2	0	0	0	0	1	1	0				
G	-	-	-	1	5	7	0	2	0	0	0	-	-	-	-	0	0	-				
CG	-	-	-	1	5	7	0	2	0	0	0	-	-	-	-	0	0	-				
BG	-	-	-	1	3	4	0	2	0	0	0	-	-	-	-	0	0	-				

In January 2019, an epidemic of Flu also occurred at JCGA. After winter vacation, students returned to the dormitory and started taking classes. At that time, there were 109 undergraduate students. On Thursday January 9, six students developed Flu. Finally, 13 students, 11 sophomores and 2 juniors developed Flu. Developed students are shown by "I" in Table 3 (Case C). According to a former study[1], I filled in the state of students such as "S"," E", "P" and "R", as well. F, C, B, Y, I, P, G, CG and BG are the same as in Table 1. Here, the base time is 10:00.

Though six students were the source of the infection bringing Flu, super-spreading didn't occur. This case is similar to after D-day in Case A and B. Compared to Case A, I found that some factors were effective.

- No big lecture for all students: students cannot contact many students.
- No martial arts: students cannot contact physically.
- Small number of students at JCGA: students can distance from each other.

Table 3. Epidemic of Flu at JCGA in January, 2019 (Case C).

ID	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	F	C	B	Y
1	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	2	1	1	O
2	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	1	1	0	O
3	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	1	1	0	O
4	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	1	1	0	O
5	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	1	1	0	O
6	S	E	P	P	**I**	I	I	I	I	I	R	R	R	R	R	R	R	R	1	1	0	O
7	S	S	E	P	P	I	I	I	I	I	I	R	R	R	R	R	R	R	0	0	0	O
8	S	S	E	P	P	I	I	I	I	I	I	R	R	R	R	R	R	R	0	0	0	O
9	S	S	E	P	P	I	I	I	I	I	R	R	R	R	R	R	R	R	0	0	0	O
10	S	S	S	E	P	P	I	I	I	I	I	I	R	R	R	R	R	R	0	0	0	X
11	S	S	S	E	P	P	I	I	I	I	I	I	R	R	R	R	R	R	0	0	0	X
12	S	S	S	S	S	S	S	E	P	P	I	I	I	I	I	I	R	R	0	0	0	U
13	S	S	S	S	S	S	S	S	E	P	P	I	I	I	I	I	I	R	0	0	0	O
I	0	0	0	0	**6**	9	11	11	11	11	5	4	2	2	2	2	1	0				
P	0	0	6	9	5	2	0	0	1	2	1	0	0	0	0	0	0	0				
G	-	-	2	0	0	0	-	-	0	0	0	-	-	-	-	-	-	-				
CG	-	-	1	0	0	0	-	-	0	0	0	-	-	-	-	-	-	-				
BG	-	-	1	0	0	0	-	-	0	0	0	-	-	-	-	-	-	-				

6. Infectivity Rate

At JCGA, infectivity rate β by "I" is 0 because patients are isolated in a sick room. Then, I calculated infectivity rate α by "P" in classroom and bedroom, as for by D-day (α_bC and α_bB) and after D-day (α_aC and α_aB)(Table 4). I found that the average infectivity rate after D-day is smaller than that of D-day. Especially the average infectivity rate in the classroom after D-day (α_aC) is one twentieth of that of D-day (α_bC). Considering that most students are affected in classrooms, that is a significant impact on the epidemic. The measures against Flu seem to be effective after D-day. It seems that Flu has finished super-spreading by D-day.

I show the average infectivity rate in the former study in Table 4, as well[1]. The standard deviation of the infectivity rate after D-day (α_aC and α_aB) is smaller than that of the former study. They approach real data more than the former study after D-day. While, those by D-day (α_bC and α_bB) have a very wide range, it is possible to provoke a pandemic by D-day.

Table 4. Infectivity rate by "P" of JCGA 2017 Case .

Infectivity rate	Classrooms		Bedrooms	
This study	by D-day α_bC	after D-day α_aC	by D-day α_bB	after D-day α_aB
Range	0 – 0.32	0 – 0.0185	0 - 0.286	0 - 0.167
The Average	0.0423	0.00190	0.0391	0.0152
Standard Deviation	0.0886	0.00489	0.0853	0.0430
Former study[1]	α_C		α_B	
The Average	0.0206		0.0259	
Standard Deviation	0.0637		0.0660	

7. Conclusion

B y examining affection by pre-infectious students in real data, I found that super-spreading depends on the timing of penetration. I show the students that super-spread seasonal influenza according to the day the first patients are discovered. According to the data, on average it takes for days for seasonal influenza measures to be implemented within the communities.

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Authors Introduction

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She is Professor of Department of Maritime Safety Technology at Japan Coast Guard Academy. She received her B.E. degree in applied chemistry engineering from Utsunomiya University and her M.S. and Ph.D. degree in computer science from National Defense Academy, Japan. She is interested in complex theory, evolutionary games.